

Experimental Observation of Amplification by Interaction Between Two Electron Streams

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The construction and performance of an amplifier employing the interaction between two streams of electrons having different average velocities are described. Gain of 33 db at a center frequency of 255 Mc has been observed with bandwidth of 110 Mc between 3 db points.

1. INTRODUCTION

A NEW type of amplifier in which the gain is obtained by an interaction between streams of electrons of two or more average velocities is proposed in a companion paper by Pierce and Hebenstreit.¹ This amplifier contains input and output portions in which signals are impressed on and extracted from the electron flow by electromagnetic circuits and a central portion in which gain occurs purely by interaction between streams of electrons without any circuits being involved. A small signal theory for coincident electron streams of two d-c. velocities is presented in Pierce and Hebenstreit's paper.

In this paper a description of the construction and operation of an amplifier of this kind will be presented. Departures of the actual conditions in the amplifier from the assumptions of the theory limit the expectations of quantitative agreement. It is believed, however, that the evidence for gain arising from the interaction between two streams of electrons is clear, and that the broad frequency response predicted by the theory has been confirmed.

2. DESCRIPTION OF AMPLIFIER

The frequency range near 200 Mc was chosen for the first experimental test of the proposed method of amplification for reasons of convenience. The theory indicates that current density requirements increase with frequency, but that these requirements become severe only at the higher microwave frequencies. Availability of circuit parts and test equipment, rather than anticipated difficulties at higher frequencies, led to the choice that was made.

The essential features of one of the double-stream amplifier tubes which has been constructed and operated are represented in Fig. 1. The output helix was identical with the input helix in construction and connection

¹A New Type of High Frequency Amplifier, J. R. Pierce and W. B. Hebenstreit, this issue of the *B. S. T. J.*

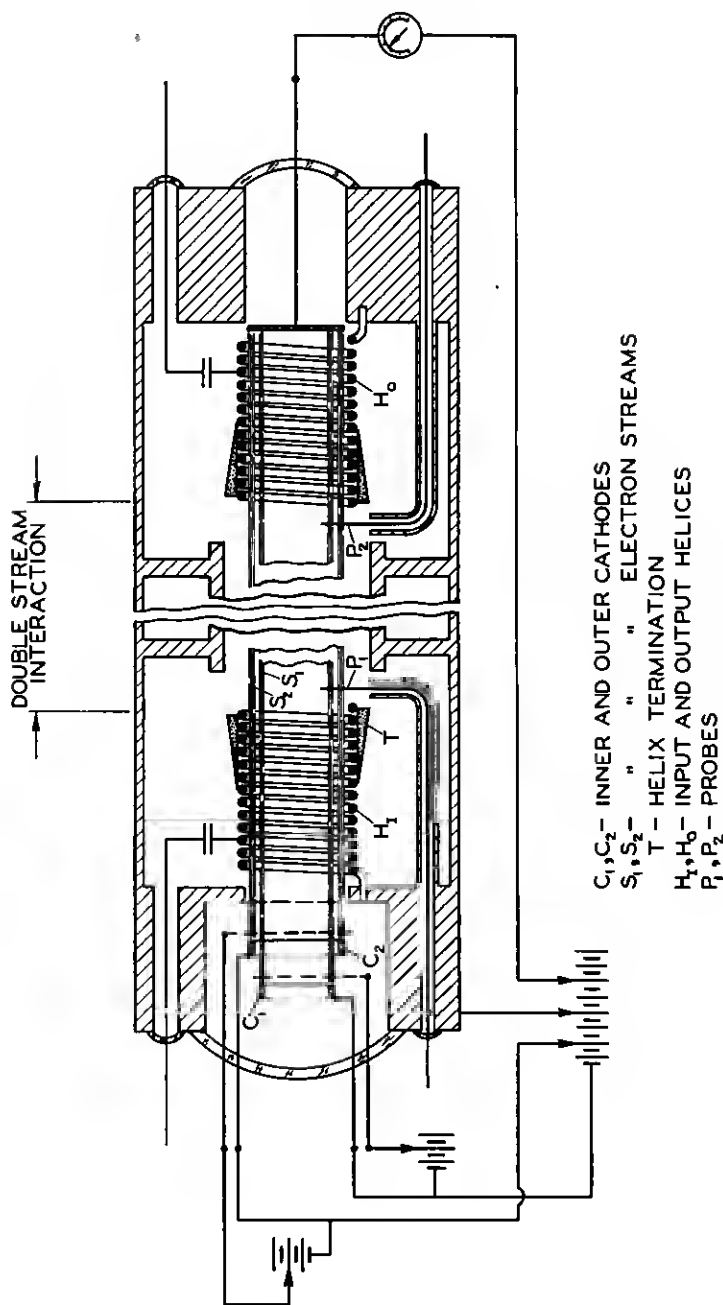


Fig. 1—Representation of double-stream amplifier with helix output.

to the coaxial line. The two identical probes p_1 , and p_2 , extending from coaxial lines into the two electron streams at the beginning and end of the central portion of the tube between the two helices were inserted for comparison of the signal amplitudes at the beginning and end of the region in which no circuit is present.

A similar tube containing an output gap in place of the output helix section is represented in Fig. 2.

In both cases concentric tubular electron streams originate at the ring-shaped emitting surfaces of the two cathodes at potentials V_1 and V_2 , pass through their respective control grids and through a common accelerating grid. An axial magnetic field of approximately 700 gauss is applied in order to maintain the definition of the beams. The outer and inner tubular beams

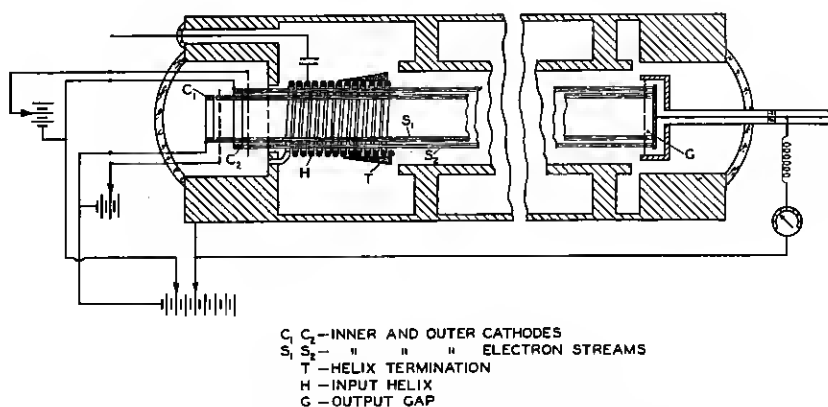


Fig. 2—Representation of double-stream amplifier with gap output.

have mean radii of 0.215" and 0.170" respectively and a wall thickness of 0.030" in each case.

The short sections of helix which are used for input and output are wound of 0.013" diameter molybdenum wire, 44 t.p.i., and mean diameter of 0.500". The axial velocity of signal propagation along this helix is equal to that of 54-volt electrons. The helix sections are each 2" long. Ceramic supporting rods on each helix section are sprayed with aquadag, over $1\frac{1}{2}$ " of their length on the end nearest the center of the tube, for terminating purposes. The thickness of the spray coating increases toward the center of the tube. The distance between helices is 8.7".

The gain produced by the electronic interaction depends upon a difference in velocity between the two electron streams. The signal is impressed upon one of the streams by the helix when its velocity is that at which traveling wave amplifier interaction between the stream and the helix occurs. It

is required, therefore, for this helix that one of the streams travel at a velocity corresponding to a potential in the neighborhood of 54 volts. Useful interaction occurs from 50 to 60 volts. The inner stream is adjusted for helix interaction in this amplifier, and the outer stream travels at a lower velocity to bring about the interaction between the two streams. Operation about a mean voltage of about 50 volts was planned in designing the amplifier, and in estimating its expected performance. The amplifier is 16 wavelengths long in terms of the wavelength associated with a mean voltage of 50 volts and a frequency of 200 Mc. Eleven of these wavelengths are in the center portion between the helices.

The conditions in the amplifier tube differ from those assumed in the derivation of the theory of the double-stream interaction in the following significant ways:

1. The beams are separated in space and not completely intermingled. Calculations on the effect of this separation have been made. Numerical examples of the calculated magnitude of the effect on gain will be given below.
2. Hollow tubular beams are used, instead of "solid" beams of uniform current density over their cross-sectional area. The theory indicates that, for the beam dimensions and currents used here, the parameters which depend upon beam radius and total current in the beam are nearly the same whether the current is concentrated in an infinitely thin cylindrical shell or uniformly distributed over the cross-section of a cylinder of the same radius.
3. The metal wall surrounding the beams is not infinitely remote. Its diameter was chosen as a compromise between the requirements of preventing serious d-c. space charge depression of potential in the beam and of being far enough removed from the beam to prevent a large effect on the interaction due to its presence. Its proximity tends to increase the minimum current required for producing gain, and therefore to reduce the ratio of actual to critical current on which the gain depends.
4. The beams are not perfectly confined to hollow cylinders of the dimensions given. There is evidence that some spreading outside of these dimensions occurs. The currents reaching the collector can be measured and these are used as "beam currents" in the discussion to follow and in comparisons between theory and experiment. Somewhat larger currents than these were initially launched, and the lost fraction may have contributed to the interaction before striking the walls.

Although the assumptions of the theory are not fulfilled in the actual amplifier, estimates of its performance were first made without correction for the discrepancies. With voltages of 40 and 60 volts on the outer and

device was very large, for the velocity of the outer beam was far from that at which interaction with the helices occurs.

A signal from the probe at the end of the central portion of the tube 23 db greater than that from the probe at the beginning of this section was observed in a comparison of the second type. This can probably be taken as a measure of the increase in signal in this portion of the tube due to the double-stream interaction alone, although the probe arrangement may also be subject to some remaining complicating effects. Overall gain for the device in this measurement was 32 db. Further interaction of the same kind occurs in the portions of the tube outside of the space between the probes.

Measurements of the gain of an amplifier with helix output as a function of velocity separation between the streams have been made. For fixed mean voltage and current, theory predicts an increase in gain from zero db at zero separation to a maximum and then a decrease to zero as the velocity separation is further increased. A maximum gain was observed experimentally as velocity separation was varied, and in the neighborhood of the predicted optimum value of velocity separation for the current used.

In the amplifier tube with gap output it was possible to evaluate the a-c. component of current in the electron stream produced by the amplified signal since the impedance across the gap was known. The power output from this tube at saturation was 0.1 mw, a little less than the maximum shown in Fig. 3. For 75 ohm output impedance this power corresponds to 1.15 milliamperes r.m.s., or about one third of the total d-c. current to the collector in both streams. The output power, although relatively low, is thus of the right order of magnitude for the currents used.

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